NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WEATHER PROGRAMS

The National Aeronautics and Space Administration (NASA) Headquarters Weather Support Office has continued to improve NASA's weather support capabilities for both manned and unmanned space launch vehicles. It is expected that these improvements will strengthen and enhance the information provided to the ground-based decision-makers and astronaut observers to insure that NASA achieves the best operational posture for Space Shuttle launches and landings. The goal of the operations program is to provide the specialized meteorological data needed by operational forecasters at Cape Canaveral Air Station of Kennedy Space Center (KSC) and Johnson Space Center to support the Space Shuttle program. The focus is on detecting and forecasting the mesoscale weather events which strongly impact Shuttle ground processing, launches, and landing operations. NASA's also performs aviation research to improve safety, develop weather information technologies, and increase aviation system capacity. Advanced operations technologies can increase the number of operations per runway in all weather conditions. The research applies to both commercial and general aviation.

OPERATIONS

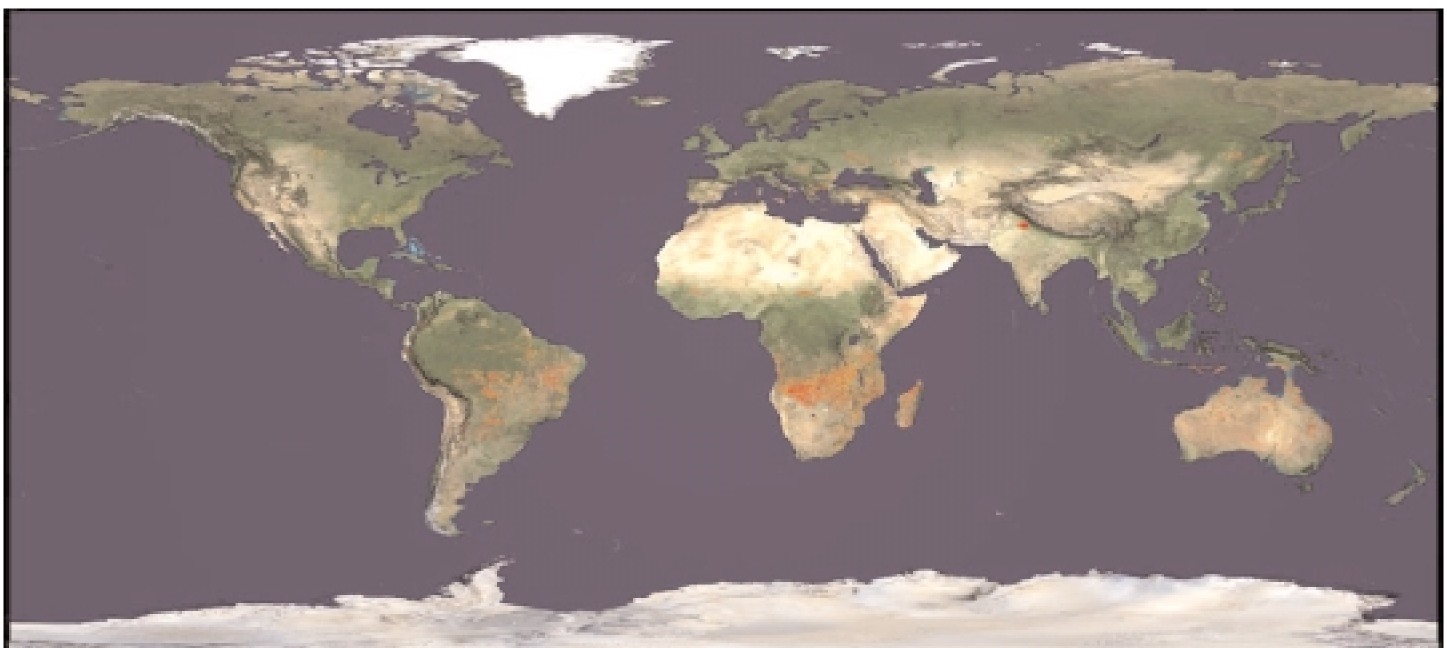
The goal of the National Aeronautics and Space Administration (NASA) weather operations program is to provide the specialized meteorological data and techniques needed by forecasters at Cape Canaveral Air Station and the Spaceflight Meteorology Group at Johnson Space Center (JSC) to support the Space Shuttle and Expendable Launch Vehicle (ELV) programs. The greatest challenge is to observe and forecast the mesoscale weather events that strongly impact ground processing, launch, and landing operations.

This goal requires exploitation of the latest technology. The Applied Meteorology Unit (AMU), co-located with the Air Force's Range Weather Operations, provides a facility to develop, evaluate, and, if warranted, transition new meteorological technology into operations. For instance, the AMU strives to develop techniques and systems to help predict and avoid the impacts of Kennedy Space Center's (KSC) frequent thunderstorms which endanger the ground processing, launch, and landing operations of the American Space Program-Space Shuttle, DOD, and commercial. The AMU has focused special attention on evaluating mesoscale numerical models. The AMU functions under a joint NASA, Air Force, and National Weather Service (NWS) Memorandum of Understanding. AMU tasks during FY 2002 include:

(a) Development and evaluation of statistical forecast tools for peak winds.

(b) Evaluation of the Eastern Range Dispersion Assessment System/ Regional Atmospheric Modeling System (ERDAS/RAMS).

(c) Development and evaluation of land breeze forecast methodologies.



(d) Development and evaluation of thunderstorm anvil forecast methodologies.

(e) Evaluation and implementation of a Local Data Integration System (LDIS) at JSC's Spaceflight Meteorology Group (SMG) and the NWS office in Melbourne, Florida.

(f) Comparison of relative humidity soundings from the Automated Meteorological Profiling System (AMPS) with those from the current Meteorological Sounding System (MSS) and analysis of the impact of any differences on Eastern Range thunderstorm forecast indices.

The KSC Weather Office is improving the KSC weather infrastructure and conducting research to improve operational processes and facilities. In FY 2002, KSC completed installation of five suites of visibility and soil moisture sensors to the west of KSC to aid in the forecast of morning fog that could impact Shuttle landings. The Weather Office also completed data gathering for a major field research program called the Lightning Launch Commit Criteria (LLCC) program using an Airborne Field Mill (ABFM) aircraft and other weather sensors to collect data necessary to relax the lightning launch constraints while making them even safer. LLCC was cooperatively funded by the Shuttle program, NASA ELVs and the USAF. The team includes more than 50 personnel from eleven organizations including other Governmental agencies, NASA Centers, universities and their contractors. Data analysis is currently underway and the initial set of new launch rules is expected by the end of FY 2003.

The KSC Weather Office, SMG at JSC, and the AMU continue to work on Range Standardization and Automation (RSA) and the new Spacelift Range Systems Contract (SLRS-C). RSA is a major Air Force program to modernize the Eastern and Western Range infrastructure. SLRS-C will provide sustaining engineering for the systems RSA provides. Deliveries of weather sensors, models, and control and display systems began in FY 2000 and will conclude in 2003. Transfer of the KSC 50 MHz Doppler Radar Wind Profiler (DRWP) to the Eastern Range and modernization of its electronic components is planned for late FY 2002 and early FY 2003. KSC is seeking funding to also improve the drainage of the DRWP antenna field that can flood during very heavy rains.

Many issues remain with RSA's pending changes to the Eastern and Western Ranges' meteorological infrastructures. Thus, the Air Force and NASA weather communities continued to expend significant resources to solve potential major deficiencies since NASA Kennedy Space Center, Johnson Space Center, and Marshall Spaceflight Center depend heavily on this infrastructure for their weather support. A major success was the RSA contractor's decision to discard their proposed Control and Display system, and instead partner with NOAA's Forecast Systems Laboratory to deliver a COTS AWIPS (Automated Weather Information System). This will provide Range Weather Operations a system that is cost effective, and compatible with both future AWIPS upgrades and with SMG.

The procurement of three Hypersodars for high-resolution wind measurements near the Shuttle Landing Facility flight path was cancelled due to funding limitations in the Shuttle Launch Site Equipment budget.

To ensure proper weather support for a NASA Athena II launch from Kodiak Launch Complex (KLC) Alaska, NASA worked with the Air Force 45th Weather Squadron (45WS) to improve the KLC weather infrastructure. The facility's only meteorological systems were two 10-meter weather towers and a balloon system. NASA and the Air Force identified a Launch Weather Officer from 45WS, a weather radar, lightning detection system, field mills at KLC and Kodiak City NWS office, and weather reconnaissance aircraft. The equipment was procured and installed prior to vehicle and payload delivery, and was critical to ensuring accurate, timely weather support to numerous weather sensitive daily ground processing and launch day operations.

The Radio Automatic Theodolite System (RATS) used to provide upper level winds, temperatures and humidity at the Shuttle Transatlantic Abort Landing (TAL) sites in Spain, Morocco, and Gambia, became obsolete when the manufacture announced cessation of sonde production. A replacement system, the Global Positioning System (GPS) based Sippican W9000, was selected, procured, integrated and tested with the help of the Eastern Range.

SUPPORTING RESEARCH

The supporting research activities are sponsored by the NASA's Earth Science Enterprise (ESE). The mission of NASA's Earth Science Enterprise is to develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations. NASA brings to this endeavor the vantagepoint of space, allowing global views of Earth system change. NASA is a provider of objective scientific information, via observation, research, modeling, and applications demonstration, for use by decision-makers in both the public and private sectors. NASA has been studying the Earth from space from its beginnings as an Agency. These efforts have led to our current activity of deploying the first series of Earth Observing System (EOS) satellites that will concurrently observe the major interactions of the land, oceans, atmosphere, ice, and life that comprise the Earth

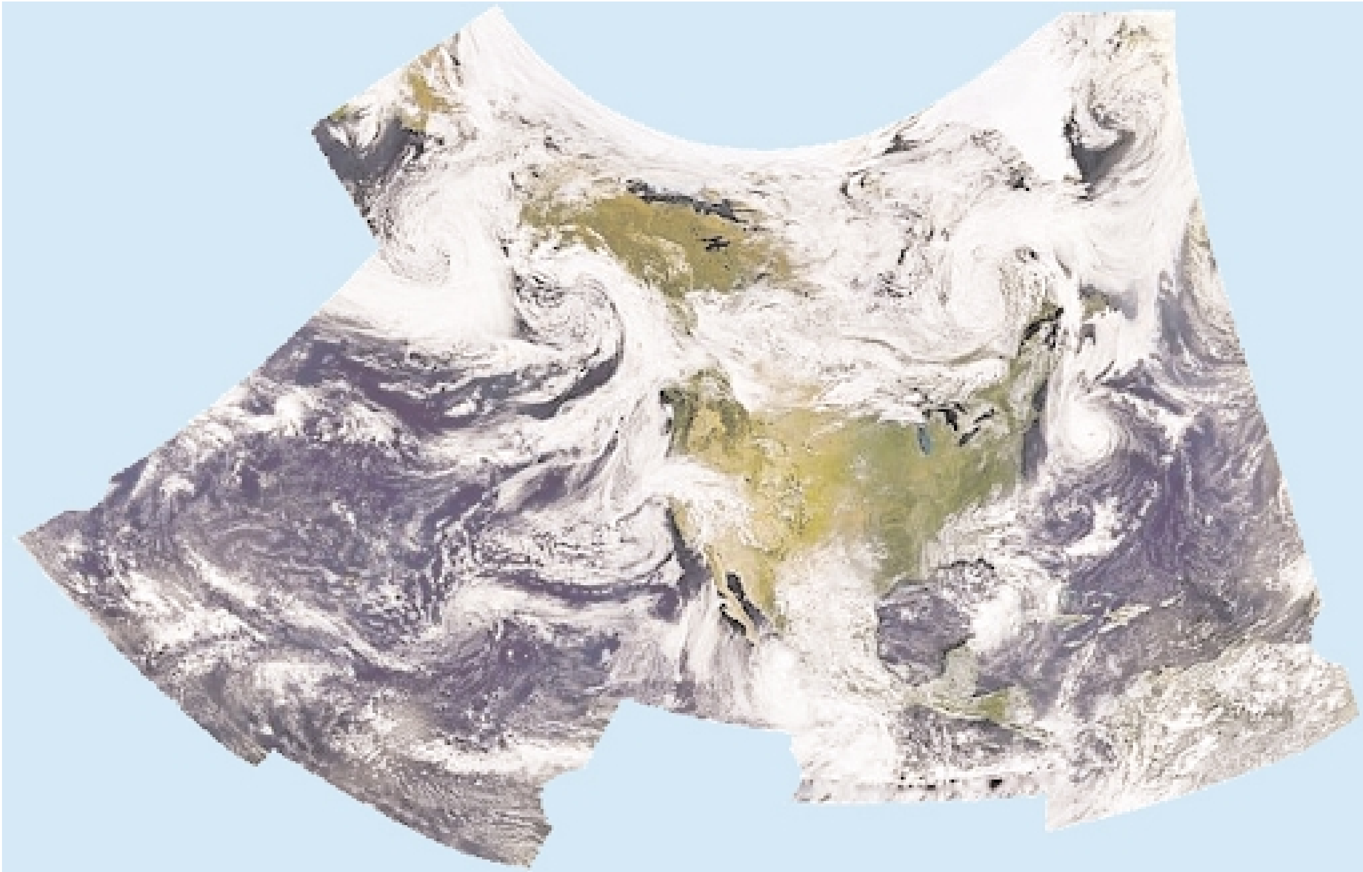


Figure 3-NASA-1. NASA's SeaWiFS captures a "Portrait of America" on September 11, 2001. (Source: GSFC web site).

system. In short, the purpose of the ESE is to provide scientific answers to the fundamental question:

How is the Earth changing, and what are the consequences for life on Earth?

A fundamental discovery made during the 20th Century, enabled in large part by NASA's global view from space, is the existence of a multiplicity of linkages between diverse natural phenomena and interactions between the individual components of the Earth system. As a result, NASA has worked with other agencies to develop a new, interdisciplinary field of "Earth System Science", with the aim of investigating the complex behavior of the total Earth environment in which the global atmosphere, the oceans, the solid Earth, the ice-covered regions of the Earth, and the biosphere all function as a single interactive system (Figure 3-NASA-1). Earth System Science is an area of research with immense benefits to the nation, yielding new knowledge and tools for weather forecasting, agriculture, water resource management, urban and land use planning, and other areas of economic and environmental importance. In concert with other agencies and the global research community, ESE is providing the scientific foundation needed for the complex policy choices that lie ahead on the road to sustainable development. ESE has established three broad goals through which to carry out its mission.

1. Science: Observe, understand, and model the Earth system to learn how it is changing, and the consequences for life on Earth;
2. Applications: Expand and accelerate the realization of economic and societal benefits from Earth science, information and technology;
3. Technology: Develop and adopt advanced technologies to enable mission success and serve national priorities. These goals are articulated in the ESE Strategic Plan.

NASA and its partners have already made considerable progress in understanding the Earth system. With satellites launched over the past decade, ESE has charted global ocean circulation including the waxing and waning of El Niño, mapped land cover change over the entire globe, illuminated the 3-D structure of hurricanes, and explored the chemistry of the upper atmosphere, as well as the causes of ozone depletion. With deployment of the EOS now underway, ESE is opening a new era in Earth observation from space in which the major interactions of the Earth system are studied simultaneously to provide a global view on climate change. With this knowledge, NASA and its partners will develop prediction capabilities to quantify the effects of natural and human induced changes on the global environment. Operational agencies, such as National Oceanic and Atmospheric Administration (NOAA) and United States Geological Survey (USGS), who are partners in this effort, can use these capabilities to improve weather and climate forecasting, natural resource management, and other services on which the nation relies.

STRATEGY FOR ACHIEVING GOALS

SCIENCE

We know that natural and human-induced changes are acting on the Earth system. Natural forces include variation in the Sun's energy output and volcanic eruptions, which spew dust into the atmosphere and scatter incoming sunlight. Human forces include deforestation, carbon emission from burning of fossil fuels, methane and soil dust production from agriculture, and ozone depletion by various industrial chemicals. Internal climate factors such as atmospheric water vapor and clouds also introduce feedbacks that serve to either dampen or enhance the strength of climate forcing. We also know the climate system exhibits considerable variability in time and space, i.e., both short and long term changes and regionally specific impacts. For example, we have observed that over the past twenty years, the growing season has lengthened in much of the northern latitudes while Arctic sea ice extent has experienced a net decrease. Behind these net changes are considerable variations by region. Recent research has shown that dust aerosols in the atmosphere tend to slow the rate of evaporation and precipitation, while rising temperatures are expected to accelerate them. Distinguishing trends in the midst of substantial variability and countervailing forces, and distinguishing natural from human-induced changes, pose some of the challenges undertaken by ESE.

NASA has used the concept of Earth System Science in developing its program. Researchers have constructed computer models to simulate the Earth system, and to explore the possible outcomes of potential changes they introduce in the models. This way of looking at the Earth as a system is a powerful means of understanding changes we see around us. This has three implications for Earth Science. First, we need to characterize (that is, identify and measure) the forces acting on the Earth system and its responses. Second, we need to understand the source of internal variability: the complex interplay among components that comprise the system. Finally, by combining observations, research and modeling, we create a capability to predict Earth system change to help our partners produce better forecasts of change.

Earth system changes are global phenomena. Yet the system comprises many micro-scale processes, and the most significant manifestations are regional. Thus, studying such changes requires a global view at regionally discerning resolutions. This is where NASA comes in, bringing the unique capability to study planet Earth from the vantage point of space. To characterize the forces acting on the Earth system and its responses, understand the source of internal variability and predict Earth system change, NASA must observe the Earth, conduct research and analysis of the data, model the data and synthesize the information into new knowledge. Where we are on this knowledge "life cycle" determines the strategy for our investment decisions. The ESE is pursuing a targeted research program, focused on a set of specific science questions that can be addressed effectively with NASA's capabilities. ESE formulates comprehensive research strategies that can lead to definitive scientific answers and potentially to effective applications by other entities.

The key Earth Science research topics sponsored by NASA follow from this view of the Earth as a system. Thus, they are grouped into categories of variability in the Earth System, forces acting on the Earth system, responses of the system to change, consequences of change, and prediction of future changes. Complicating this seemingly linear construct is a set of feedbacks; responses to change often become forces of additional change themselves. This conceptual approach applies in essence to all research areas of NASA's ESE and is particularly relevant to the problem of climate change, a major Earth Science-related challenge facing our nation and the rest of the world. The ESE has articulated an overarching question and a set of strategic science questions reflecting this Earth system approach, which its observational programs, research and analysis, modeling, and advanced technology activities are directed at answering.

How is the Earth system changing, and what are the consequences for life on Earth?

- How is the global Earth system changing? (Variability)
- What are the primary causes of change in the Earth system? (Forcing)
- How does the Earth system respond to natural and human-induced changes? (Response)
- What are the consequences of changes in the Earth system for human civilization? (Consequences)
- How can we predict future changes in the Earth system? (Prediction)

ESE's Research Strategy for 2000-2010 describes NASA's approach to answering these questions. The intellectual capital behind ESE missions, and the key to generating new knowledge from them, is vested in an active program of research and analysis. Over 1,500 scientific research tasks from nearly every state within the United States are funded by the ESE research and analysis program.

Scientists from seventeen other nations, funded by their own countries and collaborating with United States researchers, are also part of the ESE program. These researchers develop Earth system models from Earth science data, conduct laboratory and field experiments, run aircraft campaigns, develop new instruments, and thus expand the frontier of our understanding of our planet. ESE-funded scientists are recognized as world leaders in their fields, as exemplified by the award of the 1995 Nobel Prize in chemistry to two scientists who first recognized that chlorofluorocarbons provided a threat to upper atmospheric ozone. The research and analysis program is also the basis for generation of application pilot programs that enable universities, commercial firms, as well as state and local governments to turn scientific understanding into economically valuable products and services.

APPLICATIONS

NASA expects that expanded scientific knowledge of Earth processes and the utilization of advanced space-based and airborne observing techniques or facilities developed by NASA lead to practical applications beneficial to all citizens. Examples of these applications include: quantitative weather and hydrologic forecasts over an extended range of one to two weeks; prediction of seasonal or longer-range climate variations; the prediction of impacts of environmental changes on fisheries, agriculture, and water resources; global air quality forecasts and natural hazards risk assessments. NASA ESE has a role in demonstrating the potential applications.

ESE continues to build a viable applications program that bridges focused research and analysis and mission science investments towards demonstration of new remote sensing data products for industry, as well as regional and local decision makers. The emphasis is on helping weather forecasters, natural resource managers, disaster preparedness managers, and other decision and policy makers at the Federal, State and local levels to incorporate Earth science information in to their own decision support systems. The baseline Applications program provides the essential tools and funds key demonstration projects. A series of regional workshops have been held around the nation. These workshops enable a wide variety of State and local government users to share the challenges they face and explore the use of satellite remote sensing tools to address their challenges.

One result is the establishment of regular, open, competitively selected opportunities for these organizations to propose partnerships with NASA, academia and industry. These partnerships will demonstrate new applications of Earth science data to specific problems. Successful demonstrations are expected to lead to new commercial as well as state and local government transactions, while ESE moves on to the next new demonstration activity.

TECHNOLOGY

In addition to ensuring a robust science program, this budget contains a focused Technology Program that supports development of key technologies to enable our future science missions. The baseline Technology Program includes the New Millennium Program (NMP), Instrument Incubator and advanced information systems and computing elements. The Technology Program also includes a focused Advanced Technology Initiative Program that identifies and invests in critical instrument, spacecraft and information system technologies.

The ESE will lead the way in the development of highly capable, remote and in situ instruments as well as the information system technologies needed to support its science and applications objectives. Together they will enable affordable investigation and broad understanding of the global Earth system. The ESE emphasizes the development of information system architectures. These architectures will increase the number of users of ESE information from thousands to millions, with the goal of providing easy access to global information for science, education, and applications. Finally, ESE will work in partnership with industry and operational organizations to develop the capabilities and infrastructure to facilitate the transition of sustained measurements and information dissemination to commercial enterprises.

ESE's technology strategy seeks to leverage the entire range of technology development programs offering benefits in cost, performance and timeliness of future Earth science process and monitoring campaigns. ESE's strategy is to establish strong links to other government programs in order to maximize mutual benefit and to use open competitions for ESE-sponsored technology programs to attract the best ideas and capabilities from the broad technology community, including industry and academia.

Technology investments will be made in the following areas:

- Advanced instrument and measurement technologies for new and/or lower cost scientific investigations;
- Cutting-edge technologies, processes, techniques, and engineering capabilities that reduce development, operations costs, and mission risk that support rapid implementation of productive, economical, and timely missions;
- Advanced end-to-end mission information system technologies that will have an impact on the data flow from origination at the instrument detector through data archiving. These technologies will collect and disseminate information about the Earth system and enable the productive use of ESE science and technology in the public and private sectors.

Tropical Rainfall Measuring Mission

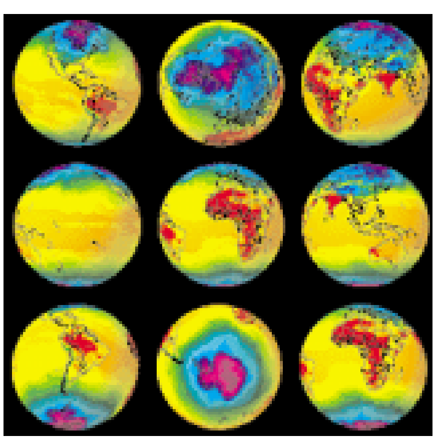
The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between NASA and the National Space Development Agency (NASDA) of Japan designed to monitor and study tropical rainfall and the associated release of energy that helps to power the global atmospheric circulation shaping both weather and climate around the globe.

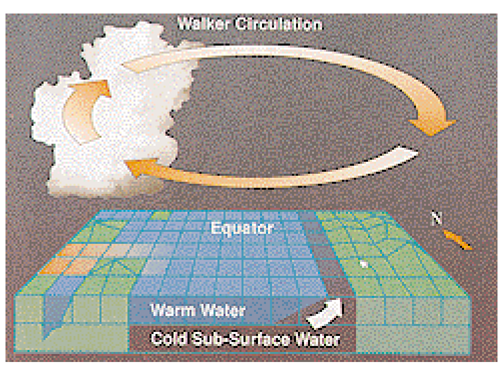
The accurate measurement of the spatial and temporal variation of tropical rainfall around the globe remains one of the critical unsolved problems of meteorology. TRMM, during its three-year mission and broad sampling footprint between 35°N and 35°S, will provide the first detailed and comprehensive dataset on the four dimensional distribution of rainfall and latent heating over vastly under-sampled oceanic and tropical continental regimes. Combined with concurrent measurement of the atmosphere's radiation budget, estimates of the total diabatic heating will be realized for the first time ever on a global scale.

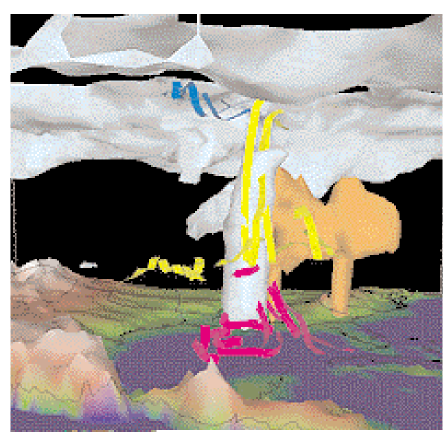
TRMM will fill many gaps in our understanding of rainfall properties and their variation. These include: (a) frequency distributions of rainfall intensity and areal coverage; (b) the partitioning of rainfall into convective and stratiform categories; (c) the vertical distribution of hydrometeors (including the structure and intensity of the stratiform region bright band); and (d) variation of the timing of heaviest rainfall - particularly nocturnal intensification of large mesoscale convective systems over the oceans, and diurnal intensification of orographically and sea-breezed forced systems over land. TRMM will enable mapping of larger time and space variations of rainfall in quasi-periodic circulation anomalies, such as the Madden-Julian oscillation in the western Pacific and ENSO over the broader Pacific basin. Furthermore, the critical onset of large annual circulation regimes, such as the Asian summer monsoon, can be more thoroughly studied.

Cumulus heating is the principal driver of regional and global-scale atmospheric circulations. For example, it is known that the phase speed of the intraseasonal oscillation (ISO) is highly sensitive to the height of the condensation heating maximum. Diagnostic budgets of sensible heat source (as inferred from research networks of soundings) are incomplete in their global coverage and inadequate to describe the large day-to-day variations that occur in the tropics. Nor can these networks completely capture the significant structural variations that occur in heating and cooling profiles between convective and stratiform rainfall regions. Intensive and globally-distributed observations from TRMM, however, will be crucial for the formulation of reliable cumulus parameterization schemes contained in the latest generation of global cloud models (GCMs).

Sensitivity tests using assimilation of latent heating estimates in GCMs has revealed the potential for improving the prediction of rainfall events. For example, GCM 24-hour rainfall predictions using initial conditions adjusted from simulated profiles of TRMM latent heating may be improved by as much as 30 percent over NMC and ECMWF models.







MISSION IMPLEMENTATION

The pursuit of Earth System Science would be impractical without the continuous, global observations provided by satellite-borne instruments. NASA's Earth science research program comprises an integrated slate of spacecraft and suborbital measurement capabilities; data and information management systems to acquire, process, archive and distribute global data sets; and research and analysis projects to convert data into new knowledge of the Earth system (Figure 3-NASA-2). Numerous users in academia, industry, as well as federal, state, and local governments use this knowledge to produce products and services essential to achieving sustainable development. The ESE top priority continues to be the commitments to launch the first series of EOS and selected Earth Explorer missions that are nearing completion. In addition, ESE is committed to evolving functioning data and information systems to support the processing, archival, and distribution of data products for these missions. These satellites will propel the ESE into a new era of data collection, research, and analysis for which both the national and international Earth science community has been preparing over the last decade.

PARTNERSHIPS ARE ESSENTIAL TO SUCCESS IN EARTH SCIENCE

The challenge of Earth System Science, sustainable development, and mitigating risk to people, property and the environment from natural disasters, requires collaborative efforts among a broad range of national and international partners. NASA's Earth science research program constitutes its contribution to the United States. Global Change Research Program (USGCRP), an interagency effort to understand the processes and patterns of global change. The USGCRP coordinates research among ten United States government agencies.

NASA is the major partner in the USGCRP, providing the bulk of the USGCRP space-based observational needs. NASA will also participate in the Climate Change Research Initiative (CCRI) announced by the President in June 2001. The CCRI will focus on answering key gaps in knowledge, will adopt performance metrics for

Figure 3-NASA-2. Landsat 7 captures an image of Manhattan, September 12, 2001. The picture shows a smoke plume spreading over large portions of the surrounding urban area. (Source: GSFC web site).

accountability, and will deliver products useful to policymakers in a short timeframe (2-5 years). NASA has extensive collaboration with the NOAA on weather and climate-related programs. The ESE is the responsible managing agent in NASA for the development of the NOAA operational environmental satellites. NOAA, NASA, and the Department of Defense (DOD) are working together to achieve the convergence of civilian and military weather satellite systems and extend selectively some observations required by climate research to the future operational systems. NASA collaborates with the USGS on a range of land surface, solid Earth and hydrology research projects. NASA and USGS continue to collaborate on the Landsat-7 program. In addition, NASA participates in the international programs of World Climate Research, the International Geosphere/ Biosphere, and the World Meteorological Organization.

International cooperation is an essential element in the Earth science program. Earth science addresses global issues and requires international involvement in its implementation and application. Acquiring and analyzing the information necessary to address the science questions is a bigger task than a single nation can undertake. Furthermore, the acceptance and use of the scientific knowledge in policy and resource management decisions around the world require the engagement of the international scientific community. Global data and global participation are needed to devise a global response to environmental change. In addition, integrating our complementary science programs can result in fiscal benefits to the NASA program. For this reason, NASA has sought and nurtured international partnerships spanning science, data and information systems, and flight missions. Most of the ESE satellite missions have international participation, ranging from simple data sharing agreements to joint missions involving provision of instruments, spacecraft, and launch services. In the past three years over 60 international agreements have been concluded and more than 40 more are pending. In some capacity, Earth science programs involve international partners from over 35 nations, including Argentina, Armenia, Australia, Belgium, Brazil, Canada, Chile, China, Denmark, Egypt, France, Germany, India, Israel, Italy, Japan, Mongolia, Russia, South Africa, Ukraine, and others.

In order to structure the scientific research, the ESE has established goals, objectives, research focus areas and programs. The ESE is currently developing roadmaps for how to achieve its science objectives. Until the roadmaps are completed, the phrase "increase understanding" is being used as a placeholder in the research focus areas.

THE EOS PROGRAM

The EOS Program provides a broad range of systematic and survey type observations and measurements to improve our understanding of the Earth system. This improved understanding, combined with improvements in predictive Earth system models, will provide the government and the public with the basis for formulating scientifically well founded environmental and resource management policies.

The EOS Program consists of the following key elements:

(1) Multiple flights to collect measurement sets that contribute to answering the science questions using instruments such as spectrometers, sounders, and radiometers.

(2) Data systems and network facilities to command and control spacecraft and instruments; to process data; and to archive, distribute and manage NASA's Earth science data.

(3) Algorithm development activities to produce the algorithms and software needed to generate the standard data products.

These data products will support the Earth System Science research needed to accomplish the ultimate objectives of the Enterprise. The measurements to be made by these and other future Earth science missions as well as current on-orbit missions provide data products that are used extensively in the Earth science program. These activities are providing an ever-increasing scientific understanding of the global environment and the effects of natural and human sources of change.

The overall goal of the Earth Observing System (EOS) Program is to advance the understanding of the entire Earth system on a global scale by improving our knowledge of the components of the system, the interactions between them, and how the Earth system is changing. The EOS data will be used to study the atmosphere, oceans, cryosphere, biosphere, land surface, and solid Earth; particularly as their interrelationships are manifested in the flow of energy and in the cycling of water and other chemicals through the Earth system.

The objectives of the EOS Program are to develop, launch, and operate remote sensing missions that will provide long-term observations in the area of climate as well as terrestrial and marine ecosystems. The EOS Program will use these observations to provide the supporting information systems necessary to develop a comprehensive understanding of how the Earth functions as a unified system and solve practical problems of interest to society.

The key research topics studied by NASA's ESE fall largely into five categories: variability, forcings, responses, consequences, and prediction. This conceptual approach applies in essence to all research areas of NASA's Earth science program, although it is particularly relevant to the problem of climate change, a major Earth science-related issue facing the countries of the world.

PROGRAM STATUS/NOTIFICATIONS/PLANS THROUGH 2002

The top priority continues to be the existing near-term commitments with the safe and effective implementation of the EOS first series, including the launches of Sorce and Icesat in FY 2002. Aqua was successfully launched in May 2002. Also in FY 2002, ESE plans to continue development of NPP and begin/continue formulation activities for a Landsat Data Continuity Mission (LDCM), global precipitation, the observation of global ocean topography and ocean surface winds to succeed TRMM, Jason-1, and SeaWinds on ADEOS II, respectively.

PROGRAM PLANS FOR 2003

In parallel with deploying EOS, NASA ESE is looking ahead to determine the important Earth science questions in the next decade that require NASA's unique capabilities and leadership to be answered. Drawing on existing reports of the National Academy of Sciences and the state of progress in current scientific endeavors, ESE has developed a Research Strategy for this decade that articulates a hierarchy of one overarching question, five broad subordinate questions, and twenty-three detailed questions that can and should be tackled over this decade. ESE is in the process of developing roadmaps for each of the detailed questions. Some of those roadmaps may indicate the need for definition of candidate missions.

The opportunity to hand off a required measurement to an operational agency is one of the criteria that were used to identify missions funded in the FY 2003 budget request. Therefore, a high priority in this timeframe is the National Polar-Orbiting Operational Environmental Satellite System (NPOESS) Preparatory Program (NPP). NPP will serve to provide continuity with the Terra and Aqua missions as well as a demonstration of instruments for the converged weather satellite program. NASA and the Integrated Program Office (IPO) jointly fund the NPP mission. The IPO consists of representatives from the three agencies participating in NPOESS - NASA, the NOAA, and the Air Force. The follow-on to JASON also falls into this category. Another priority is the Landsat Data Continuity Mission (LDCM) to succeed Landsat-7 as required by the Land remote Sensing Policy Act of 1992 to maintain the continuity of Landsat-type data beyond Landsat-7 into the New Millennium. As with Landsat-7, this mission is being planned in partnership with USGS and the private sector. NASA and USGS plan to implement LDCM as a commercial data purchase and have released a request for proposal from industry for Landsat-type data to meet data continuity requirements. In FY 2003, there will be a pause in the development of other proposed satellites, pending a review of the USGCRP, and its relationship to the new CCRI.

SPACE WEATHER

The Living With A Star (LWS) Program (Figure 3-NASA-3) addresses the linkage between three fundamental questions of the NASA solar-terrestrial physics program's the Sun Earth Connection (SEC) program:

- *How and why does the sun vary?*
- *How does the Earth respond to solar variations?*
- *How does solar variability affect life and society?*

The SEC Program strives to understand the physical processes and connections that control the dynamics of the Sun-Earth connected system. The system dynamics are driven by violent solar bursts, long term solar variability, and instabilities of the magnetized Earth-space, geospace. LWS is grounded in service to humanity and it's technological systems. It is based on solving the specific problem of being able to predict solar variations and the effects of those variations on humanity and human systems. LWS will integrate results from existing and future space missions as they contribute to the SEC system level goals. The program is based on providing the understanding necessary to predict what will happen where and when to the heliosphere, geospace, and Earth's climate given observations of conditions on the Sun.

While both existing SEC programs and LWS are basic research, there are some significant differences in concept and approach. The primary difference is that in addition to the traditional input from the space science community, LWS derives requirements from Earth science, human spaceflight, industry and other federal agencies (National Space Weather Program, Office of the Secretary of Defense Space Weather Architecture, DOD, NOAA, FAA). The LWS Program has characteristic features: there is a significant component that deals with specification models; what is the environment as a function of space and time. This is an important need for industry that must build spacecraft that survive, and to provide anomaly resolution. There is a need for human spaceflight radiation protection. Finally, there is the issue of prediction, which is the more traditional science.

The program priorities are (numbers indicate priority rank):

(1) Solar influences on Global Change: Global change is the single most important environmental problem facing humanity. This issue involves major national and international policies because of the potential economic impacts of global change and/or mitigation actions. Objectives:

- Determine how and why the Sun varies (for assessment of past and future role in global climate change).
- Identify and understand mechanisms by which solar variability

affects terrestrial climate (and possibly weather).

(2) Space environmental "climate" data (e.g., specification models):

- Needed for design of cost-effective systems with minimal or no sensitivity to space weather.
- The goal is to have economical "all weather" systems; not to be dependent on predictions.

(3) Nowcasting space environment:

- For rapid anomaly resolution for space and communication/navigation systems--if an anomaly is due to a known space environmental effect, it is often possible to get back into operation rapidly. If it is due to an unknown cause, it may be necessary to do detailed failure analysis--requiring extended downtime of the affected system.
- Astronauts safety--in the event of significant radiation, astronauts can move to shielded areas.

(4) Prediction of:

- Solar Proton Events (astronaut/airline flight safety). Goals: (a) reliable warnings (minimize false alarm rate) and (b) reliable forecast of "all clear" periods for EVA's.
- Prediction of geomagnetic storms for applications where effective mitigation is possible (e.g. electric power grid). Goals--reliable forecasts (storm is coming) and very reliable shorter term (~hour) warnings to minimize unnecessary mitigation by reducing capacity, etc. which can reduce system efficiency.
- Predictions of space environment for operation and utilization of space systems. Goals: (a) reliably forecast availability/accuracy/sensitivity of communication and navigation systems susceptible to space weather (e.g., ionospheric scintillations) and (b) enable optimization of systems and the allocation of resources during times of extreme space weather conditions.

In summary, LWS will characterize the space environment with the aim being to help spacecraft designers and operators, and address astronaut health and safety. LWS will produce the system knowledge to predict solar effects on climate, and solar/geospace effects on human systems in space and on the ground.

The approach to achieving our goals is to treat the Sun, heliosphere, and geospace as a system. The key to dealing with the problem as a system is to understand that physics-based models will be the "glue" that holds the system together. It is assumed that ultimately reliable and serviceable models combined with key observations of the SEC system will allow the prediction of what will happen--where and when. Model requirements will drive what observations are needed for boundary conditions and "truth" tests of the models.

The present approach to implementing a systems-based program is to define the management structure along scientific problem lines. The space environment research area includes the effects of solar variability on climate and global change as well as specification of radiation and density models. The space storms area includes the specification of the environment on a more real-time or nowcasting and event basis. Included as well is the ultimate goal of the LWS, the physical understanding of the end-to-end Sun-Earth system, enabling reliable predic-

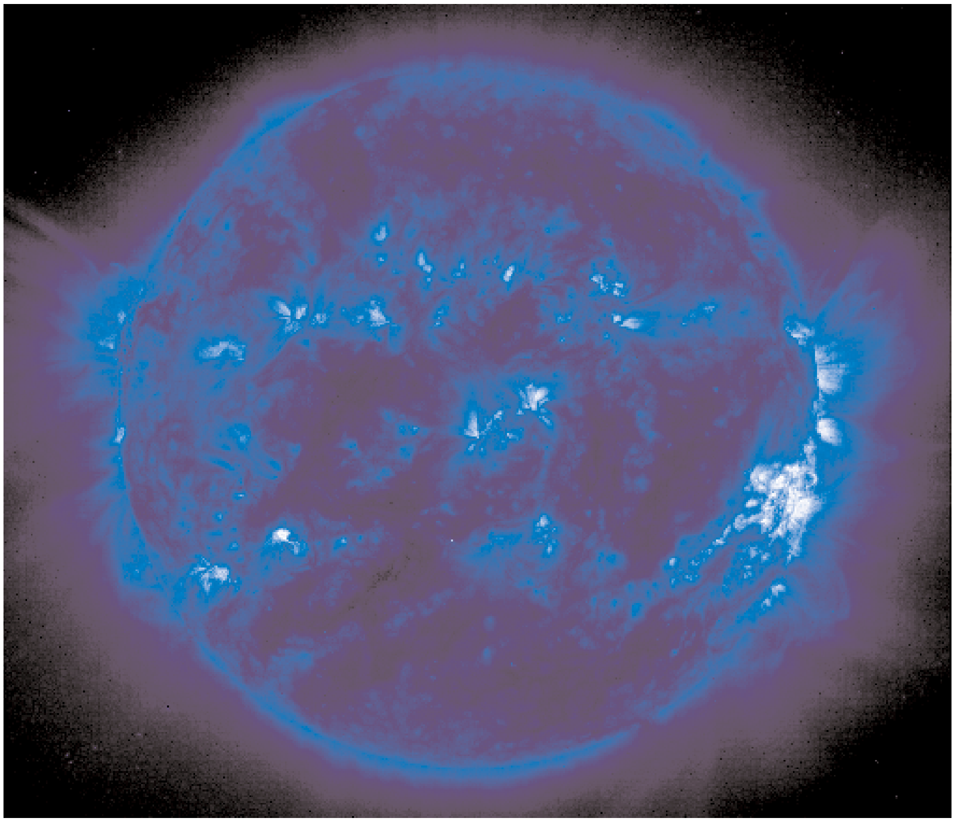


Figure 3-NASA-3. This image is a picture of the Sun taken by the Extreme Ultraviolet Imaging Telescope on board the SOHO spacecraft. This particular image is of the lower corona and is produced by the emission of energetic UV light by iron particles in the solar atmosphere. Iron only emits this sort of light if it is very hot. In the case shown here we are looking at gas with a temperature of around 1. million degrees. Bright regions on the main body of the Sun are called active regions. When these active regions reach the edges of the solar disk (the solar limbs) the display a number of interesting features called coronal loops. The small bright regions which are strewn across the disk of the Sun are called bright points while the large dark regions are called coronal holes.

tive capability of storm effects. The program has the following elements: (1) a Space Weather Research Network of solar-terrestrial spacecraft; (2) a theory, modeling, and data analysis program; and (3) Space Environment Testbeds (SET) for flight testing radiation-hardened and radiation-tolerant systems in the Earth's space environment. Vital to the success of LWS and critical to the satisfaction of national needs is the development of partnerships with national and international agencies and industry.

Implementation of LWS will proceed in two phases. The first phase will include: (1) a geosynchronous spacecraft that will observe the Sun from its interior (via helioseismology techniques) to the outermost extensions of its atmosphere where solar activity produces the variable solar output of electromagnetic radiation, solar wind, and energetic particles, and (2) the Geospace Mission, a set of spacecraft to understand geospace as a function of time and the effects of solar events and local instabilities on its evolution. The second phase will add a set of heliospheric spacecraft to determine the state of the solar wind and the propagation of events.

AVIATION SAFETY PROGRAM

NASA's Aviation Safety Program is aggressively pursuing several areas that will provide weather information, avoidance, and mitigation technologies, and education and training aids. The following elements are included:

- Aviation Weather Information (AWIN) develops technologies that provide high fidelity, timely, and intuitive information to pilots to enable the detection and avoidance of atmospheric hazards (Figure 3-NASA-4).
- Weather Information Communications (WINCOM) develops advanced communication technologies and architectural concepts to provide weather information, avoidance, and mitigation technologies, icing design and analysis tools, icing education and training aids, and accurate and timely weather information to the cockpit for both national and international flight.
- Turbulence Prediction and Warning System (TPAWS) develops airborne turbulence warning systems and associated crew procedures to mitigate upsets from all types of turbulence encounters, including clear air turbulence (CAT).
- Aircraft Icing (AI) addresses critical technology gaps in ice prediction, detection, avoidance, and mitigation capability to reduce safety hazards, aviation system throughput impacts, cost of air travel, and design cycle time.

The project will:

- develop validated analytical and experimental tools for design and certification/qualification of aircraft systems in icing;

Figure 3-NASA-4. NASA and aviation industry vendors have developed an initial Aviation Weather Information (AWIN) system which is graphical and intuitive for ease of use. Designed to replace bulky, text printouts, AWIN will put graphical weather information in the cockpit.

- develop improved predictions, forecasting, and resolution of in-flight icing conditions;
- better understand the effects of ice contamination on aircraft performance, stability and control, and handling qualities;
- develop ice protection systems, including ice sensing, prevention, and removal;
- develop methods for avoiding in-flight icing hazardous conditions by using remote sensing technologies and flight deck information management; and
- develop icing related educational materials and training aids for pilots, airline operators, and dispatchers.

Synthetic Vision Systems (SVS): NASA is developing "synthetic" (electronically enhanced) vision for the pilot (Figure 3-NASA-5). It combines a very detailed worldwide terrain map (obtained from Space Shuttle mapping missions), precise GPS navigation data, and integrity-monitoring sensors to provide a 3-dimensional, realistic view of the world through a cockpit head-up-display (HUD) or instrument panel-mounted display. The pilot will look through the HUD as he or she looks out the window. This see-through HUD will make the world look like a bright sunny day even when the airplane is approaching a fogged-in airport at midnight--one that would be shut down under today's operating rules. NASA believes that improving the pilot's situational awareness will largely eliminate controlled-flight-into-terrain (CFIT) and runway incursion accidents. NASA is also evaluating the use of modified weather radar and FLIR for runway object detection.

Limited visibility is the single most critical factor affecting both the safety and capacity of worldwide aviation operations. In commercial aviation, over 30 percent of all fatal accidents worldwide, and the leading cause of total fatalities, are categorized as controlled flight into terrain -- accidents in which a functioning aircraft impacts terrain or obstacles that the flight crew could not see. In addition, the largest general aviation accident category is 'Continued Flight into Instrument Meteorological Conditions', in which

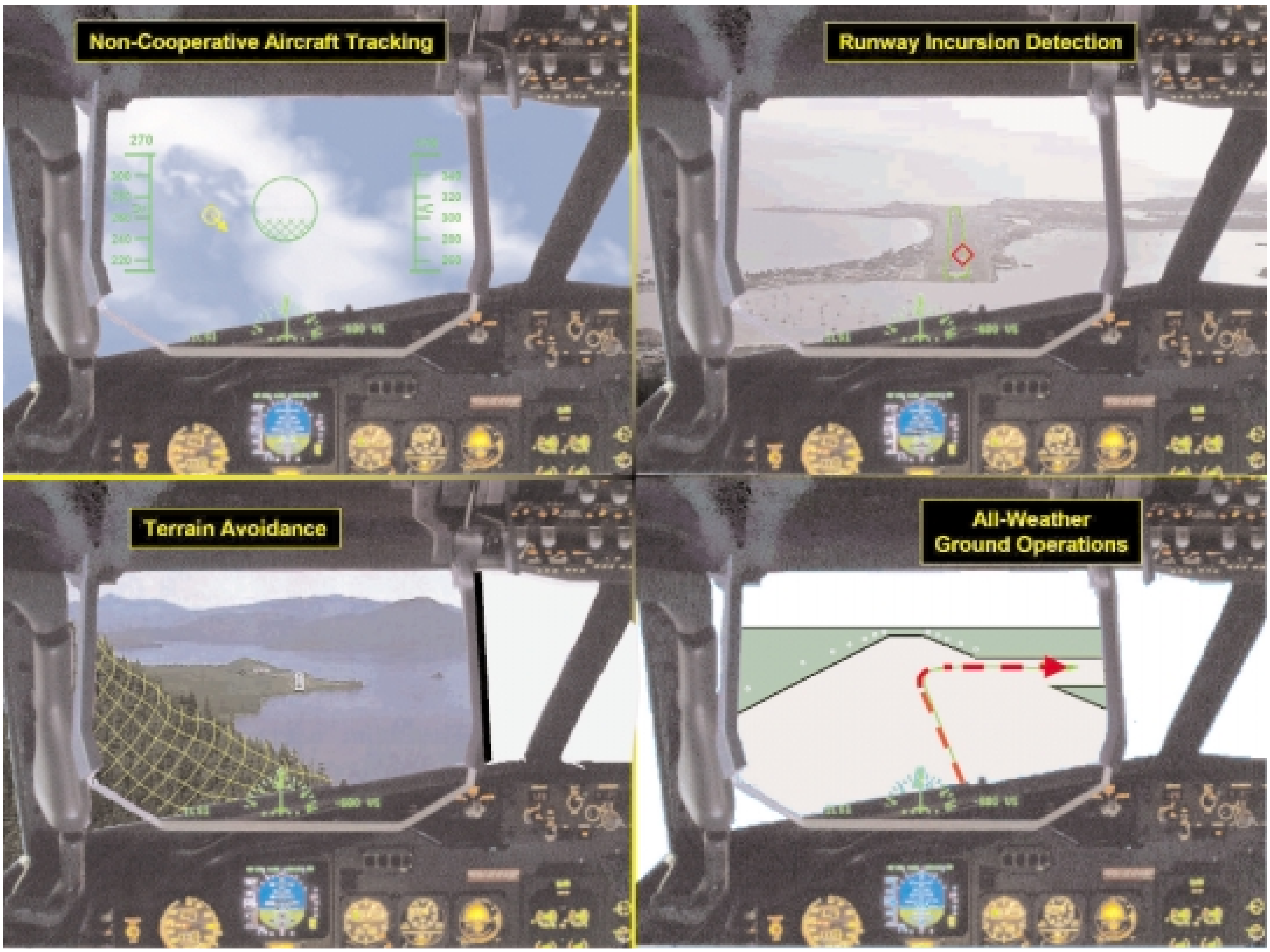


Figure 3-NASA-5. Four examples of synthetic vision systems which enhance a pilot's vision through heads-up displays.

low-experience pilots continue to fly into deteriorating weather and visibility conditions and either collide with unexpected terrain or lose control of the vehicle because of the lack of familiar external cues. The goal of the synthetic vision work is to achieve VMC capability in IMC (to Category IIIB).

GENERAL AVIATION

NASA's Small Aircraft Transportation System (SATS) research program will demonstrate technology to safely guide a small aircraft in near all-weather conditions to virtually any small airport in non-radar, non-towered airspace (Figure 3-NASA-6). The elements are:

- Higher Volume Operation at Non-Towered/Non-Radar Airports will enable simultaneous operations by multiple aircraft in non-radar airspace at and around small non-towered airports in near all weather conditions through the use of vehicle-to-vehicle collaborative sequencing and self-separation algorithms and automated flight path management systems.
- Lower Landing Minimums at Minimally Equipped Landing Facilities will provide precision approach and landing guidance, through the use of graphical flight path guidance and artificial vision, to any touchdown zone at any landing facility while avoiding land acquisition and approach lighting costs, as well as ground-based precision guidance systems, such as ILS.
- Increase Single-pilot crew Safety and Mission Reliability will increase single-pilot safety, precision, and mission completion through the use of human-centered automation, intuitive and easy to follow flight path guidance superimposed on a depiction of the outside world, software enabled flight controls, and onboard flight planning/management systems.
- En Route Procedures and Systems for Integrated Fleet Operations will provide an analytical assessment of the impact of automated flight path management systems designed to facilitate operations at non-towered airports and in non-radar airspace on the integration of SATS equipped aircraft into the higher en route air traffic flows and controlled terminal airspace.

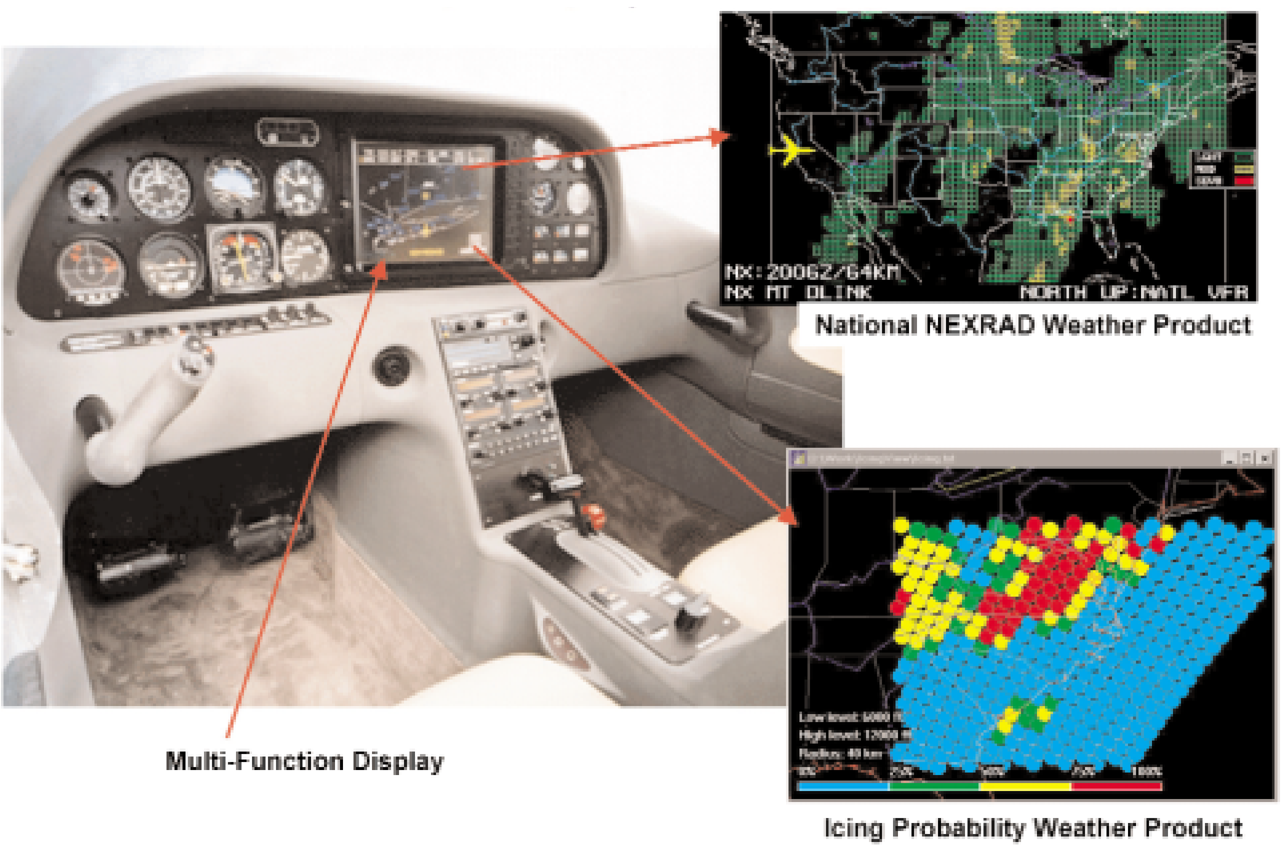


Figure 3-NASA-6. General Aviation cockpit display of weather information.